

# Surface state density on the ZnTe and $\text{Cd}_{0.98}\text{Fe}_{0.02}\text{Te}$ free surfaces

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The conditions for calculating the surface states density from the measurements of the surface photovoltage versus temperature are discussed. The results of the calculations for ZnTe and  $\text{Cd}_{0.98}\text{Fe}_{0.02}\text{Te}$  surfaces are presented.

## 1. Introduction

The surface photovoltage technique is widely applied to determining minority carriers diffusion lengths [1] and detecting heavy metal contaminants in semiconductors [2], as well as to image of the surface charge at the semiconductor surface [3]. The detailed carriers balance model of the surface photovoltage (SPV) [4] shows that a rigorous treatment of generation and recombination processes are essential. It has been found that for cases of low surface recombination, a saturated SPV is a good approximation of the surface potential value. Thus a dependence of SPV versus temperature can be a base to obtain the surface state density function [5], if the surface generation velocity is high. A qualitative approach considering the influence of an additional majority carriers generation via quantum tunneling on the measured surface state density is presented in this paper.

## 2. Theory

In the p-type semiconductor with positively charged surface, the surface charge region (SCR) is depleted and negatively charged. The absolute values of both charges are equal and it means that the surface is in thermal equilibrium with the bulk. The surface charge is assumed to be composed of two parts (see Fig. 1): positively charged donor-like surface states with the invariable charge located far above the surface Fermi level, and negatively charged acceptor-like surface states situated near the top of the valence band. The total surface charge can be changed only because of the electron exchange from/into the acceptor states. The pathway for electrons to the surface-bulk exchange via quantum tunneling is not commonly discussed. When the surface potential is positive and high, the electrons can tunnel from the bulk into the surface states located under the top of the bulk valence band (Fig. 1). The steady

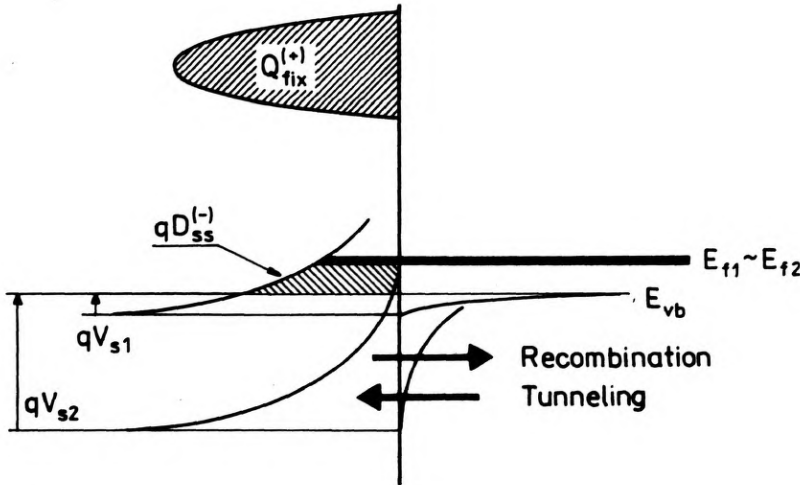


Fig. 1. Cut-down effect on the density of surface states

state occupation of the acceptor states will be established when the thermal and tunnel generation currents are equal to the thermal recombination current. It means that the surface states are dynamically delocalised via quantum tunneling pathway. Finally, the observed density function of the surface states is cut down below the top of the bulk valence band (Fig. 1). Thus, from the photovoltage versus temperature data we can estimate only the effective density of surface states, *e.g.*, the density of those states which are above the top of bulk valence band in the temperature of measurement.

The effective density of surface states is proposed to be given by

$$D_{Vs} = -g/q^2 dQ_{ss}/dV_s \quad (1)$$

where  $Q_{ss}$  is the surface charge caused by surface potential  $V_s$  and  $g$  is a degeneracy factor (for acceptor-like surface state  $g = 3$ ). The differentiation ( $dQ_{ss}/dV_s$ ) can be done analytically as the theory of SCR [6] gives a relation between  $Q_{ss}$  and  $V_s$  in the thermal equilibrium. For the p-type semiconductor with the depleted SCR we have

$$D_{ss} = g \frac{1 - \exp(-v_s)}{F_s} \sqrt{\frac{\epsilon\epsilon_0 p}{qkT}} \quad (2)$$

where we use commonly known symbols,  $F_s = (2(\exp(-v_s) + (v_s - 1)))^{1/2}$  is the Kingston's function for depleted SCR and  $v_s = qV_s/kT$  is a dimensionless surface band bending.

### 3. Experiment

The SPV measurements have been done on the wide gap semiconductors ZnTe and  $Cd_{0.98}Fe_{0.02}Te$ , p-type both, in clean vacuum conditions ( $10^{-6}$  Pa), using the

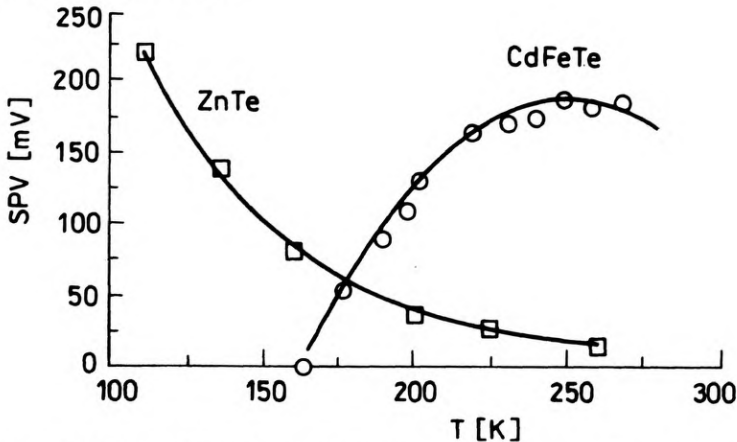


Fig. 2. Surface photovoltage versus temperature for  $\text{Cd}_{0.98}\text{Fe}_{0.02}\text{Te}$  and  $\text{ZnTe}$

self-made apparatus described elsewhere [7]. Before measurements the surfaces of the samples were polished with Gamal (Gamma Alumina A-446), rinsed in methyl alcohol and subsequently in deionized water. Figure 2 presents the decrease of SPV signal versus temperature for the  $\text{ZnTe}$  sample and increase for the  $\text{Cd}_{0.98}\text{Fe}_{0.02}\text{Te}$  ones, but the absolute changes of both signals were similar and equal to about 200 mV. The effective surface state density functions (Fig. 3) have been calculated

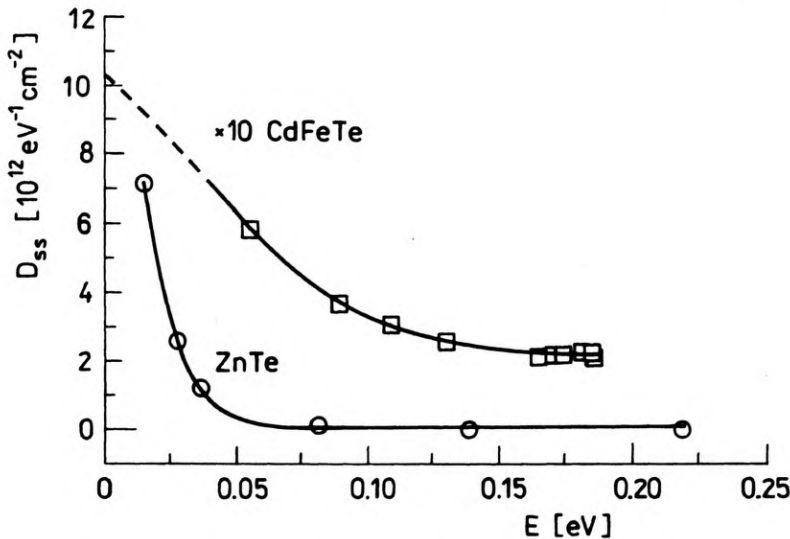


Fig. 3. Effective surface state density for  $\text{Cd}_{0.98}\text{Fe}_{0.02}\text{Te}$  and  $\text{ZnTe}$  near the top of valence band

from Eq. (2). The different bulk properties of both samples ( $p(T)$  relations) cause the similar shapes of the density functions of both samples in spite of the different character of the SPV changes with temperature. The two functions are also similar to the well known structure of semiconductor surface states with high density "tail" near the valence band edge [5], [8]. We assume that the mechanism of surface

charge changes is the same for both samples. The charge of electrons on the surface states "tail" near the top of valence band disappears (Fig. 1) when the surface potential is big, despite of the sample temperature. But the effective density of surface states for ZnTe is about ten times bigger (Fig. 3) because the temperature where it is observed is higher.

#### 4. Summary

For the explanation of results obtained for the samples under investigation the proposed model assumed that the total surface charge is composed of positive charge on the donor-like states at the upper part of the energy gap and the negative charge on the "tail" of the acceptor-like states near the top of the valence band. The charge exchange with bulk is possible only for the acceptor states. For small surface potential, present in high temperature for ZnTe and low temperature for  $\text{Cd}_{0.98}\text{Fr}_{0.02}\text{Te}$ , the acceptors "tail" is negatively charged and the total surface charge is small. For the increase of the surface potential the tail "drowns" in the Fermi sea of electrons because of delocalisations of the surface states via quantum tunneling, and then its negative charge decreases and the total surface charge increases. In other words, the density function is cut down and we can only measure its "effective" value. Presented interpretation well explains results obtained.

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